Fostering ecoliteracy through model-based instruction







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Efforts to define ecoliteracy have led to diverse theoretical frameworks for thinking about what constitutes ecoliterate thinking and behavior. Some theories emphasize the role of core values as sole predictors of ecoliteracy, whereas others suggest that ecoliteracy stems from a deep understanding of foundational ecological principles. While the attributes of ecoliteracy are under debate, college instructors are challenged to promote it in their classrooms. In 2009, Jordan *et al.* urged the ecological community to adopt discrete goals for ecoliteracy education that reflect ways of thinking characteristic of ecological science (eg modeling, inquiry, connectivity). We build from Jordan *et al.*'s (2009) argument and propose instruction that incorporates the use of scientific models as a way to target two themes that recur in virtually all definitions of ecoliteracy: "scientific habits of mind" and "ecological connectivity".

Scientific habits of mind

For decades, the literature on scientific literacy has called for instruction that fosters scientific "habits of mind" – the ability to think and reason in the same way as practicing scientists (AAAS 2011). In view of this, science educators have long advocated that learners actively engage in core practices of the scientific community to develop scientific thinking skills and understand how scientific knowledge is constructed and applied (Wyckoff 2001; AAAS 2011). As such, science instruction should model scientific inquiry by providing opportunities for students to develop and test hypotheses; analyze, interpret, and evaluate evidence; and reason from models and arguments (Handelsman *et al.* 2004; AAAS 2011). To be ecologically literate, one must also be scientifically literate; therefore, teaching that develops scientific habits of mind in the context of ecological science is consistent with the goals of ecoliteracy education.

Ecological connectivity

Ecology's distinctive emphasis on connections may result from its origins as a science that integrated multiple disciplinary perspectives. The theme of "connectivity" is further amplified by contemporary ecological research that is based on understanding *systems*. Indeed, "systems thinking" permeates the literature on ecological literacy, including ideas about order and organization, equilibrium and interdependence, and consequences of system perturbations. Therefore, ecology teachers must move away from teaching concepts as disparate ideas and toward instruction that reflects the interconnectedness that characterizes ecological systems.

Can teaching and learning with models promote ecological literacy?

In ecology, as in biology, models are foundational tools for sharing and evaluating ideas, formulating and testing hypotheses, and predicting system responses (Löhner *et al.* 2005). Ecological models reduce complexity by condensing information into simpler visual representations that focus attention on critical concepts and relationships. Despite their ubiquity in science, models and modeling are underrepresented in available pedagogical materials. We assert that model-based instructional strategies that require students to iteratively construct, apply, and evaluate scientific models will foster the development of ecoliterate thinking (WebFigure 1). Our argument is based on the following:

(1) Models reflect science as it is practiced. National reports strongly advocate learning strategies that mirror science practice (AAAS 2011), and research has shown that engaging students in the active construction and evaluation of scientific models can promote other forms of scientific thinking. For example, Löhner *et al.* (2005) showed that students developed greater proficiency in science process skills (eg formulating, testing, and evaluating hypotheses and experiments) when they actively worked with graphical models of scientific information, as opposed to text-based descriptions.

(2) Models focus thinking on connections. Instructional resources (eg textbooks, lesson plans) tend to be "modular" in nature, where units of instruction are organized around a central concept, and supporting cases, problems, and assessments facilitate instruction about that concept. Although

this approach may successfully focus faculty attention on conceptual understanding rather than "content coverage", few if any offer support for developing students' understanding about conceptual *connections*. This is particularly relevant given that a distinguishing feature separating "expert" (ie faculty, researchers) from "novice" (ie student) learners lies in the ability of experts to discern *relationships among* concepts, whereas novices focus on concepts in isolation.

(3) Models facilitate learning about complex systems. Complex ecological systems are characterized by numerous interrelated concepts that may be abstract or encompass multiple spatial and temporal scales. Interactions among system components result in emergent properties that cannot be predicted on the basis of system components. The ability to use modeling with complex systems has been identified as an expected core competency for biological literacy (AAAS 2011). Computer-based instructional tools (eg STELLA, EcoBeaker) offer unprecedented opportunities for students to visualize system connectivity and conduct quantitative analyses. However, research has shown that students need stronger fundamental model construction skills before they can take full advantage of the benefits of computer modeling (Westra *et al.* 2007). As such, model-based pedagogies that afford students practice in building conceptual connections and integrating knowledge across biological scales may help prepare students for learning in computer-based simulation environments.

(4) Models represent authentic science assessment. Multiple-choice assessments are pervasive in college-level biology courses and although they have potential to uncover important student conceptions, they are not reflective of science practice and provide limited insight into students' thinking. Essays, on the other hand, have great potential for revealing student thinking but may be an unrealistic option for instructors of large-enrollment courses. Models represent an alternative method for assessing ecological knowledge that is both authentic and capable of revealing insight into the ways students are organizing, connecting, and developing their thinking (WebFigures 2 and 3).

Conclusions and recommendations for best practices

Instructional strategies that reward students for factual recall will not help them manage the volumes of data and interconnected concepts that typify complex ecological systems, nor will they help them develop the scientific habits of mind necessary for meeting 21st-century ecoliteracy objectives. We contend that infusing ecology instruction with modeling and model-based reasoning is a step toward promoting the development of thinking skills necessary for ecoliteracy. We offer the following recommendations, based on our experiences in designing and implementing a model-based curriculum in introductory biology:

(1) Assess early, adjust accordingly. Instructors often make assumptions about students' prior knowledge and are disappointed by poor performance on exams when their expectations are not met. Pre-assessing students' modeling skills will provide insight about their proficiency in constructing and interpreting visual representations such as graphs, maps, and trend lines. These data provide a realistic benchmark from which to design instruction that builds upon students' existing skill sets.

(2) Use models as mortar, not bricks. Ecology curricula typically incorporate ecological models as discrete topics that students learn about through narrative descriptions. We argue that instead of teaching ecological models as topics, engaging students in building and reasoning about ecological models can serve as an instructional approach that creates a context for learning new content and reinforcing unifying principles. Revisiting and revising thematic models throughout a course is a powerful way of integrating new knowledge.

(3) Practice is valuable only when paired with feedback. Scientific reasoning ability is not innate but requires experience and practice. Therefore, if students are to improve their skills, they must have opportunities to practice their thinking and receive feedback. While it may not be feasible for instructors to deliver individualized feedback to hundreds of students, it is both practical and constructive to foster opportunities for peer feedback. Students can work in small groups to evaluate, test, redesign, and reason from models they have constructed. Instructors can offer guidance about specific questions or issues to focus on so that discussions are directed and productive.

We and our colleagues have implemented model-based pedagogies in introductory biology courses ranging from 18–500 students and in upper-division specialty courses (eg Restoration Ecology, Experimental Plant Biology). While proven to be a practical instructional strategy across a range of topics, models may be most powerful in ecological contexts where students are required to integrate disparate concepts and explain processes that cut across multiple scales (eg predicting consequences of environmental changes, explaining the movement of carbon through an ecosystem). Although many students struggle with using scientific models, particularly early in instruction, many report that, over time, models help them to see "the big picture" and how biological concepts are connected. In addition, by engaging students in iterative and reflective modeling experiences, we are affording students opportunities to participate directly in the assessment of their own learning. As students evaluate and revise their models to incorporate new knowledge, they are building their capacity for reasoning and critically evaluating their own understanding – skills that are essential under any definition of ecoliteracy.

References

Please see WebReferences

